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Biomechanical Properties of the Pelvic Floor and its Relation to Pelvic Floor Disorders

Alejandra M. Ruiz-Zapata [a,b,*], *Andrew J. Feola* [c], *John Heesakkers* [b], *Petra de Graaf* [d,e], *Mija Blaganje* [f], *Karl-Dietrich Sievert* [g]

[a] *Department of Obstetrics and Gynecology, Radboud Institute for Molecular Life Sciences (RIMLS), Radboud University Medical Center, Nijmegen, The Netherlands;* [b] *Department of Urology, Radboud University Medical Center, Nijmegen, The Netherlands;* [c] *Department of Biomedical Engineering, Georgia Institute of Technology and Emory University, Atlanta, GA, USA;* [d] *Department of Urology, University Medical Center Utrecht, Utrecht, The Netherlands;* [e] *Regenerative Medicine Center Utrecht, The Netherlands;* [f] *Division of Gynecology, University Medical Centre Ljubljana, Ljubljana, Slovenia;* [g] *Department of Urology, University of Rostock, Germany*

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Abstract

Pelvic organ prolapse and stress urinary incontinence remain a clinical challenge as they have unclear pathophysiology and suboptimal treatments. These common pelvic floor disorders (PFD) are characterized by the weakening of the pelvic floor supportive tissues that are directly related to their biomechanical properties. Characterizing the biomechanical properties of the pelvic floor tissues has been the focus of recent studies and researchers are using tools that are not always well understood by clinicians. Therefore, the aim of this review is to provide an overview of the most used methods to test the passive biomechanical properties of the human pelvic floor tissues. We also summarize recent findings from studies looking into the passive properties of the pelvic floor in pelvic floor disorders using the ex vivo tensile test and emerging in vivo techniques. Together, these studies provide valuable quantitative information about the different biomechanical properties of the supportive tissues of the pelvic floor under normal and pathological conditions. Results from ex vivo tests provide valuable data that needs to be correlated to the in vivo data and the clinical manifestations of the symptoms of the PFD. As more research is conducted we will obtain an enhanced understanding of the effect of age, PFD, and treatments on the biomechanical properties of the pelvic floor. This information can contribute to better identify individuals at risk, improve clinical diagnosis, and develop new treatments to advance clinical practice.

* Corresponding author. Radboud University Medical Center, Radboud Institute for Molecular Life Sciences (RIMLS), Geert Grooteplein-Zuid 26–28, 6525 GA Nijmegen, The Netherlands.
Tel. +31643760043.
E-mail address: Alejandra.RuizZapata@radboudumc.nl (A.M. Ruiz-Zapata).

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1. Introduction

Pelvic organ prolapse (POP) and stress urinary incontinence (SUI) are public health concerns and important pelvic floor disorders (PFD) affecting millions of women worldwide. Both are caused by the weakening of pelvic floor (PF) supportive tissues and occur independently or coexist. They remain a challenge because they are multifactorial conditions with unclear pathophysiology and suboptimal treatments. A woman's lifetime risk for either POP or SUI surgery is as high as 20% [1], with a substantial reoperation rate due to recurrence [2].

The supportive soft tissues within the PF are a combination of muscles, fascias, and ligaments working together to keep the pelvic organs in place in a highly dynamic environment. Biomechanical tools are used to understand how tissues function together to provide support and resist deformations. The biomechanical properties of a tissue can be active or passive and can be measured using well characterized ex vivo destructive techniques or new emerging in vivo methods. Most studies looking into the biomechanical properties of the human PF supportive tissues have reported the passive biomechanical properties. Such properties allow tissues to transmit loads or resist deformations without generating external forces. These properties are important because the PF supportive tissues are loaded and deformed by different activities and conditions that can be physiological (eg, age, parity, walking, jumping, breathing), or pathological (eg, vomiting, obesity, previous surgery, chronic coughing). Thus, changes in the biomechanical properties of these tissues and loading environment may help to better understand PFD. These fundamental understandings contribute to identify individuals at risk and to improve clinical practice and diagnosis resulting in new treatments.

There are many different terminologies and means to report the material properties of tissues. As studies grow, researchers are using different tools to characterize the biomechanical behavior of tissues that can sometimes be confusing. Therefore, the aims of this review are: (1) to provide an overview of the most frequently used methods to test the biomechanical properties of PF soft tissues in humans, (2) to review the current literature on the passive mechanical properties of the different support tissues of the human female PF, and (3) to put this information in perspective of PFD.

2. Why should we study tissue biomechanics in the pelvic floor?

The PF tissues are a combination of muscles, fascias, and ligaments that form a hammock-like support at the bottom of the abdomino-pelvic cavity that are attached to the pelvic bones. They have two basic functions: (1) to provide support to the pelvic organs (ie, the bladder, vagina, uterus, and rectum), and (2) to facilitate intercourse, vaginal delivery, storage of stool, and voluntary defecation and urination. Successful PF support is able to resist the loading environment without resulting in a pathology (eg, SUI, POP, fecal incontinence, etc.). Therefore, PF support is dependent on the loads these PF tissues experience and the biomechanical properties of the tissues themselves. A natural variation in the loading environment or material properties may make certain individuals more at risk for developing a PFD than others. For example, we can examine two individuals with high loads on their PF tissues. The first individual may not develop PFD because their tissues are able to resist these mechanical loads (forces), while the second individual has weaker tissues and thus progresses to develop a PFD. Therefore, it becomes critical to accurately understand the loading environment that these PF tissues are exposed to, and to directly characterize the biomechanical properties of the PF tissues. With this knowledge, physicians could adapt treatments according to the individual's needs for a better long-term patient care.

2.1. *The loading environment of the PF*

The PF is constantly being loaded by intra-abdominal pressure (IAP) because of its anatomical location and daily activities. The IAP is a physiological load that is transmitted from the lungs and diaphragm through the abdominal cavity and eventually onto these PF tissues. This load can fluctuate with passive or active compression of the abdominal wall, breathing, load bearing, coughing, laughing, etc. Higher loads would mean higher force increments in the IAP and therefore changes in the mechanical loadings to the PF.

Changes in the IAP have been recorded in the bladder and are assumed to be a good representation of the pressures received by the PF. The maximum intrabladder pressure for nonpregnant healthy volunteers has been reported to be as high as 347 cmH_2O during coughing and vomiting in the right lateral decubitus position [3]. Straining a stool typically leads to peak pressures of 100 cmH_2O over several seconds [4]. Obesity can further increase the baseline of the IAP by 19 cmH_2O [5]. These conditions (eg, chronic coughing, constipation, and obesity) are related to well identified risk factors of PFD and represent a profound load on pelvic organs. In addition, POP and SUI have been strongly linked with injury incurred during parturition [6]. Unsurprisingly, the maximum pressures exerted on the PF muscles are during the second stage of labor, where the already high basal levels due to the pregnancy itself, can be increased a further 194 cmH_2O [4]. Such pressures become higher than the increased IAP for coughing and straining present in nonpregnant women and may last for as long as 1 hr. The combination of these elevated loads, duration, and deformation presents a high risk for injury to the PF. Therefore, over the last decade the concept of biomechanics has become a focal point in understanding POP and SUI.

3. How are the biomechanical properties of the PF tissues being tested?

Understanding tissues' biomechanical properties facilitates access to tissues' function. Unlike traditional materials, biological tissues are complex in organization, function, and

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